USAFETAC/PR--91/024

OPTIMAL PLACEMENT OF A GEODSS (GROUND-BASED ELECTROOPTICAL DEEP-SPACE SURVEILLANCE) SENSOR

A FOLLOW-ON REPORT FOR 14 CANDIDATE SITES WORLDWIDE

by

CAPT THOMAS H. ELIO

NOVEMBER 1991

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PATRICK J. BREITLING
Chief Scientist

FOR THE COMMANDER

WALTER S. BURGMANN
Scientific and Technical Information
Program Manager
26 November 1991

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13. Abstract: A follow-on report to USAFETAC/PR--91/018, which provided site-specific data for 12 proposed Canadian Ground-Based Electrooptical Deep-Space Surveillance (GEODSS) stations. The follow-on provides much of the same general data, but with site-specific data for 14 different candidate GEODSS locations around the world. Successful operation of the system, basically an optical video camera that tracks objects in high Earth orbit, requires that the following five conditions are met: Sun at least 6 degrees below horizon; surface wind speed less than 25 knots; temperature more than -50° C; satellite elevation at least 15° above horizon; and a 5-minute cloud-free line-of-sight between satellite and sensor. This follow-on report gives the probabilities of combinations of those conditions at 14 proposed GEODSS sites; seven in Australia, four in Indonesia, and one each in Italy, the Philippines, and the Netherlands Antilles. It includes a review of fundamentals, a discussion of computer model results, and a comparison of results for each candidate location.

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PREFACE

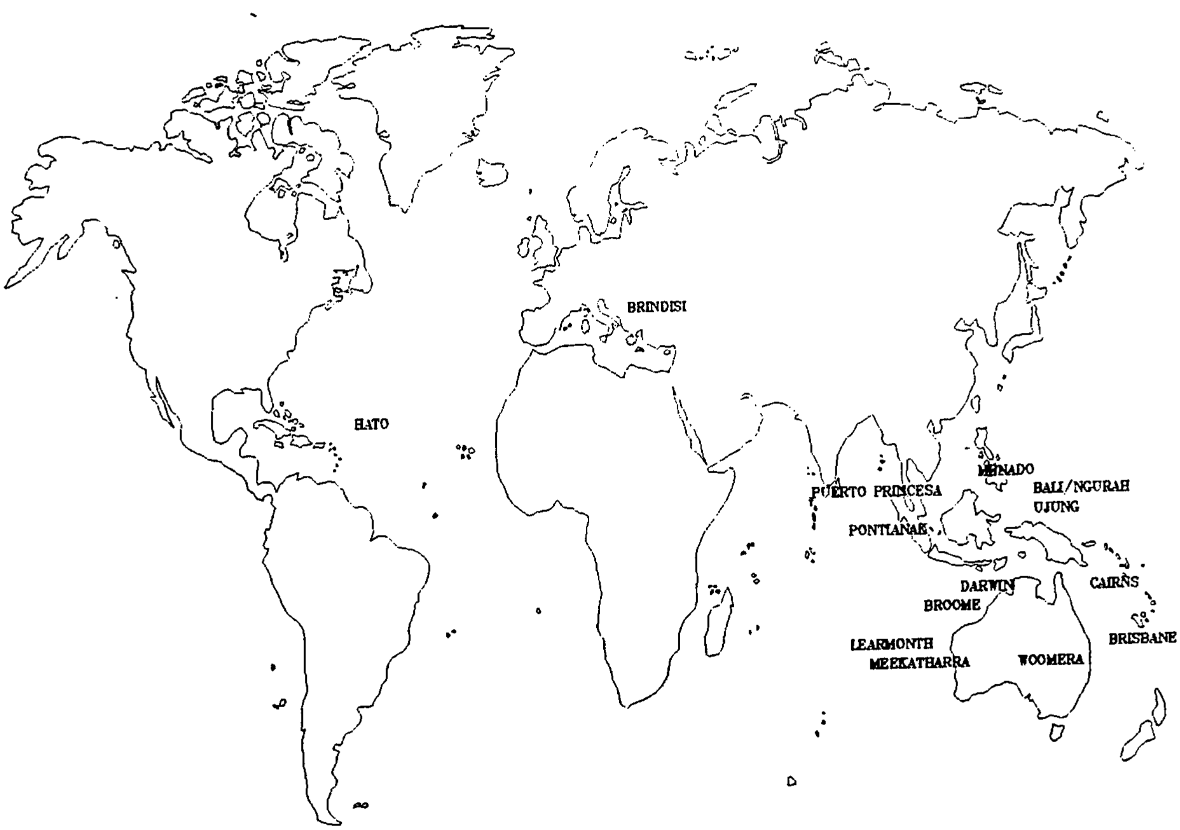
The original report documented USAFETAC Project #900833, which was in response to a support assistance request (SAR) from a Canadian AFIT student through Detachment 1, 2d Weather Squadron (ASD/WE), Wright-Patterson AFB, OH 45433-6503. The first SAR asked for the relative probabilities of certain environmental conditions at 12 Canadian locations, each a candidate for a Ground-Based Electrooptical Deep-Space Surveillance (GEODSS) sensor.

This report is in response to a tasking by Det 2, 2WS (ESD/WE), Hanscom AFB, MA, for optimum placement of GEODSS sensors worldwide. Their first SAR asked only for a study of the placement of GEODSS sensors in Australia, but a follow-on SAR asked that the study be extended to potential sites around the world. The customer's reaction to a draft of this report suggests that there will be more requests for cloud-free line-of-sight analyses inthe future.

Project analyst was Capt Thomas H. Elio, USAFETAC/DNY, DSN 576-5412.

CONTENTS

TABLES



STATION	Latitude (Deg Min)	Longitude (Deg Min)	Block Station Number
Learmonth, Australia	22° 10' S	114° 01' E	943020
Woomera, Australia	31° 06' S	136° 30' E	946590
Brisbane, Australia	27° 20' S	153° 00' E	945780
Darwin, Australia	12° 15' S	130° 28' E	941200
Broome, Australia	17° 57' S	122° 12' E	942030
Cairns, Australia	16° 53' S	145° 45' E	942870
Meekathara, Australia	26° 36' S	118° 32'E	944300
Bali/Ngurah, Indonesia	08° 45' S	115° 10' E	972300
Hasanuddin/Ujung, Indonesia	05° 04' S	119° 33' E	971800
Menado, Indonesia	01° 32' N	124° 55' E	970140
Pontianak/Supadio, Indonesia	00° 09' S	109° 24' E	965810
Brindisi/Casale, Italy	40° 39' N	017° 57' E	163200
Hato, Netherlands Antilles	12° 12' N	068° 58' W	789880
Puerto Princesa, Philippines	09° 45' N	118° 44' E	986180

Fourteen proposed sites for placement of GEODSS sensors.

1. INTRODUCTION

1.1 The GEODSS Sensor. The military mission of space surveillance is to detect, track, identify, and catalog man-made objects in space (USSPACECOMR 55-12). Radar is used to track objects in low-earth orbits (typically up to 5,000 km, but actual altitude varies depends on the type of radar). For objects at high altitudes, a global network of ground-based sensors provides observational data to the Space Surveillance Center (SSC) located at the Cheyenne Mountain complex, Colorado Springs, CO. The SSC analyzes surveillance data to determine the locations of orbiting satellites.

The sensor used for high-altitude orbit detection is the Ground-Based Electrooptical Deep-Space Surveillance (GEODSS) system, basically an optical video camera. Four GEODSS systems around the globe are currently operational, and a fifth is scheduled for Portugal. The installation of a sixth system in Canada is being considered by the United States Space Command (USSPACECOM). This report examines the suitability of 14 other candidate locations around the world; they are shown in the figure on page 1, opposite.

1.2 Environmental Effects on GEODSS. Determining the best GEODSS locations requires evaluating many criteria; these include logistics, personnel support, and environmental effects. The last (the environment) is critical because weather elements have a significant effect on GEODSS operation. For example, low temperatures and high winds prevent the exposure and operation of the antenna system. For successful detection, a cloud-free line-of-sight must be present. And since the system tracks satellites based on infrared emissions, it can only work at night. Therefore, all the following conditions (*A*-*E*) must be met for successful detection of an orbiting satellite:

A ... The Sun is at least 6 degrees below the horizon.

B... The surface wind speed is less than 25 knots.

C... The temperature is more than -50° C.

D... The satellite elevation is at least 20° above the horizon.

E... There is a 5-minute cloud-free line-of-sight (CFLOS) between sensor and satellite.

1.3 Summary. This report presents probabilities of various combinations of the conditions described by *A* through *E*. The most important of these is the probability of condition *E*, given the joint occurrence of conditions *A*, *B*, *C*, and *D*. This value describes the probability of successful detection of the satellite given that it is in view, that temperature and wind conditions are favorable, and that it is dark enough. The methodology used to estimate these probabilities is also presented. Six satellite orbits are considered: an orbiting satellite at 19,000 km with a right ascension angle of 65° (a constellation of navigational satellites populates this orbit); and five geostationary orbits with the satellites located at longitudes within clear view of the GEODSS. For example, a station located at 120° E would look at satellites at 80° E, 100° E, 120° E, 140° E, and 160° E.

2. FUNDAMENTALS

2.1 Cloud-Free Line-of-Sight. One of the requirements for successful GEODSS detection of an orbiting satellite is that there be a 5-minute cloud-free line-of-sight (CFLOS) between sensor and satellite. The climatological probability of CFLOS, therefore, is fundamental to evaluating the operational potential of a proposed GEODSS station. Because CFLOS is not reported in weather observations, a simulation model to estimate probabilities is required. The CLDGEN (Cloud Generation) model was used to estimate the 5-minute probability of CFLOS between a point on the surface and an orbiting satellite. A separate subbroutine provides the azimuth and elevation angle of the satellite as viewed from the ground. CLDGEN determines whether or not the point in the sky corresponding to the satellite location is cloud-free. The clock then advances 10 seconds, and the process repeats. The number of completely clear 5-minute intervals divided by the total number of 5-minute intervals represents the climatological probability of obtaining a 5-minute cloud-free line -of sight.

2.2 Sun-angle Constraints. Since the GEODSS is a passive electrooptical system, it can operate only in darkness; specifically, when the sun is below an elevation angle of at least 6 degrees (defined in Section 1 as condition *A*). The customer in this case, however, asked for more stringent sun-angle constraints of 12 and 18 degrees below the horizon. The former (12°) corresponds to the period between the end of *evening nautical twilight* (EENT) and the beginning of *morning nautical twilight* (BMNT); the latter (18°), to the period between the end of *evening astronomical twilight* (EEAT) and the beginning of *morning astonomical twilight* (BMAT). Conditional probabilities are computed given that condition *A* is occurring.

TABLE 1a. Median fraction of time that the Sun is at least 12 degrees below the horizon, by month.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Learmonth	.38	.38	.42	.45	.47	.47	.48	.46	.43	.40	.38	.36
Brisbane	.35	.38	.42	.45	.48	.49	.49	.47	.44	.41	.37	.34
Woomera	.34	.38	.41	.45	.49	.49	.50	.47	.43	.39	.35	.33
Darwin	.40	.41	.42	.44	.44	.45	.45	.44	.43	.42	.40	.40
Broome	.38	.40	.40	.45	.46	.47	.47	.46	.45	.42	.39	.38
Cairns	.38	.40	.43	.45	.46	.47	.47	.45	.44	.42	.39	.38
Meekatharra	.35	.39	.35	.45	.47	.49	.49	.47	.43	.41	.36	.34
Bali/Ngurah	.42	.42	.44	.43	.44	.45	.45	.45	.44	.43	.41	.41
Hasanuddin/Ujung	.42	.42	.43	.43	.44	.44	.45	.44	.44	.43	.42	.42
Menado	.43	.43	.43	.43	.43	.43	.42	.43	.43	.44	.43	.43
Pontianak	.43	.43	.43	.43	.43	.43	.43	.43	.43	.43	.43	.43
Brindisi/Casale	.51	.50	.42	.38	.31	.28	.28	.32	.40	.44	.49	.52
Hato	.45	.45	.44	.43	.40	.40	.40	.41	.43	.45	.45	.46
Puerto Princesa	.45	.45	.44	.43	.41	.40	.40	.41	.43	.44	.44	.45

TABLE 1b. Median fraction of time that the Sun is at least 18 degrees below the horizon, by month.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Learmonth	.33	.35	.38	.40	.43	.43	.43	.42	.39	.36	.33	.32
Brisbane	.31	.34	.38	.42	.44	.44	.44	.43	.39	.35	.33	.30
Woomera	.29	.32	.38	.43	.44	.45	.46	.43	.40	.35	.31	.27
Darwin	.35	.37	.38	.40	.40	.40	.40	.40	.39	.38	.36	.35
Broome	.33	.37	.39	.41	.43	.43	.40	.40	.39	.38	.35	.38
Cairns	.34	.38	.38	.41	.43	.43	.43	.43	.40	.38	.36	.35
Meekatharra	.31	.38	.38	.42	.43	.45	.44	.43	.41	.37	.33	.29
Bali/Ngurah	.38	.38	.40	.40	.41	.42	.41	.41	.40	.40	.38	.37
Hasanuddin/Ujung	.38	.40	.40	.41	.40	.45	.41	.40	.40	.40	.39	.38
Menado	.39	.40	.40	.40	.40	.39	.39	.40	.40	.40	.40	.39
Pontianak	.39	.40	.40	.40	.40	.39	.39	.40	.40	.40	.40	.39
Brindisi/Casale	.46	.42	.39	.32	.25	.20	.22	.27	.35	.41	.45	.47
Hato	.42	.42	.39	.38	.38	.35	.36	.38	.38	.40	.42	.42
Puerto Princesa	.41	.41	.40	.38	.38	.37	.37	.38	.40	.40	.40	.42

2.3 Wind Speed Constraint. As shown in Table 2, the fraction of time the surface wind speed is less than 25 knots (Condition *B*) is nearly unity for all stations for all months. Based on the near null occurrence of winds greater than or equal to 25 knots, we can assign a probability (*P*) of Condition *B* equal to unity. That is, $P(B) = 1$ for all stations.

TABLE 2. Fraction of time the wind is less than 25 knots, all hours.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Learmonth	.99	.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	.99
Brisbane	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	.99	1.00	1.00	1.00
Woomera	.99	.99	1.00	1.00	1.00	1.00	1.00	1.00	.99	.99	.99	.99
Darwin	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Broome	.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Cairns	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Meekatharra	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Bali/Ngurah	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Hasanuddin/Ujung	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Menado	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Pontianak	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Brindisi/Casale	.93	.96	.96	.98	.99	.99	.99	1.00	.99	.98	.97	.95
Hato	1.00	1.00	.99	.99	.99	.99	.99	1.00	1.00	1.00	1.00	1.00
Puerto Princesa	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

2.4 Temperature Constraints. The probability of temperatures higher than -50° C (Condition *C*) was easily determined from weather observations taken during the 1973-89 period of record (POR) for all stations. All the stations reported either every 3 or 6 hours during the entire POR. No observation of temperature lower than -50° C was found for any station under consideration; therefore, $P(C)$ is also assumed to be unity for all stations.

2.5 Satellite Elevation Constraint. The probability of condition D, $P(D)$, is the fraction of time the satellite is above an elevation of 20° above the horizon. Since geostationary satellites have a fixed location relative to an observer on the ground, this probability will be binary (either zero or one) and constant. Since these satellites are positioned over the Equator, only a latitude is necessary to specify position. Because the candidate sites are well within viewing range of these satellites, $P(D)=1$ for geostationary satellites. Table 4 depicts $P(D)$ at each site for the polar-orbiting navigational satellite.

TABLE 3. Mean fraction of time that a polar-orbiting satellite is visible at each site with a 20-degree above the horizon visibility restriction.

STATION	PROBABILITY
Learmonth	0.21
Brisbane	0.22
Woomera	0.22
Darwin	0.19
Broome	0.21
Cairns	0.21
Meekatharra	0.22
Bali/Ngurah	0.17
Hasanuddin/Ujung	0.14
Menado	0.12
Pontianak	0.11
Brindisi/Casale	0.12
Hato	0.20
Puerto Princesa	0.18

2.6 Conditional 5-Minute CFLOS Probabilities. Next we will consider the probability of a 5-minute CFLOS (condition E) given conditions A, B, C, and D, $P(E/ABCD)$. In our model, we accounted for condition A by excluding those cases between BMCT and EECT, between BMNT and EENT, and between BMAT and EEAT. It was established earlier (in 2.3) that the candidate stations rarely have winds equal to or greater than 25 knots at night; therefore, Event B is no problem because $P(B) = 1$ and we can now say that $P(E/ABCD) = P(E/ACD)$. It has also been established that temperature is not a problem because temperatures of -50° C or less are not found at any of the locations; therefore, $P(C) = 1$, and we can say that $P(E/ACD) = P(E/AD)$. Conditon D is not a problem either, since the model keeps track of satellite elevation and only samples data within the elevation constraints given.

3. MODEL RESULTS

3.1 Five-Minute CFLOS Probabilities. Tables 5 through 9 give monthly 5-minute CFLOS conditional probabilities, $P(E/ABCD) = P(E/AD)$ for six satellite configurations and Sun elevation angles for the 12 southern hemisphere stations; Tables 10 and 11 are for Hato, Netherland Antilles, and Brindisi, Italy. Table 4a and 4b are for the 19,000 km orbit with a 65° angle of inclination, for Sun angles 12° and 18° below the horizon, respectively. Note that the probabilities do not vary much beween sun angles; we can therefore assume equal probabilities (within 2-3%) for both Sun angles. Tables 5 through 9 give the conditional probabilities for geostationary orbits with the satellite located at five different positions: 80°, 100°, 120°, 140°, and 160° East longitude. Note: Tables 5-9 indicate a single set of probabilities for Brindisi/Casale, Italy, for geostationary satellite positions 20°, 40°, 60°, 80°, and 100°.

TABLE 4a. Conditional Probability of a 5-minute CFLOS for a polar-orbiting satellite, Sun angle 12° below the horizon.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Learmonth	.54	.54	.59	.59	.63	.60	.70	.75	.80	.77	.73	.68
Brisbane	.39	.40	.48	.53	.51	.58	.57	.63	.59	.48	.45	.40
Woomera	.66	.62	.66	.63	.54	.54	.57	.64	.62	.62	.62	.63
Darwin	.17	.17	.23	.42	.58	.60	.64	.62	.56	.49	.35	.25
Broome	.20	.21	.31	.54	.51	.61	.62	.68	.64	.59	.51	.39
Cairns	.34	.31	.38	.43	.41	.54	.54	.52	.52	.54	.51	.43
Meekatharra	.62	.55	.58	.61	.65	.71	.68	.71	.78	.73	.68	.65
Bali/Ngurah	.22	.26	.35	.39	.47	.45	.50	.51	.50	.44	.42	.28
Hasanuddin/Ujung	.17	.20	.24	.30	.44	.39	.54	.57	.52	.53	.39	.18
Menado	.31	.29	.36	.46	.49	.41	.46	.49	.45	.49	.47	.34
Pontianak	.20	.16	.16	.18	.24	.25	.33	.31	.16	.14	.13	.14
Brindisi/Casale	.37	.35	.38	.49	.55	.65	.79	.81	.70	.52	.47	.43
Hato	.71	.65	.54	.46	.44	.40	.49	.54	.51	.45	.48	.56
Puerto Princesa	.43	.48	.56	.55	.40	.24	.19	.21	.24	.30	.33	.37

TABLE 4b. Conditional Probability of a 5-minute CFLOS for a polar-orbiting satellite, Sun angle 18° below the horizon.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Learmonth	.54	.53	.59	.59	.64	.61	.70	.74	.81	.76	.70	.67
Brisbane	.39	.41	.47	.53	.52	.61	.57	.61	.59	.48	.46	.41
Woomera	.68	.66	.67	.65	.55	.55	.59	.64	.62	.65	.61	.64
Darwin	.16	.18	.23	.43	.61	.60	.65	.63	.57	.52	.36	.26
Broome	.20	.21	.31	.53	.51	.61	.62	.68	.63	.60	.52	.39
Cairns	.34	.31	.38	.43	.41	.54	.54	.52	.52	.54	.51	.42
Meekatharra	.61	.54	.57	.60	.64	.70	.67	.71	.78	.73	.67	.64
Bali/Ngurah	.21	.25	.36	.38	.48	.45	.50	.51	.49	.43	.41	.28
Hasanuddin/Ujung	.16	.19	.23	.30	.43	.38	.53	.56	.51	.52	.39	.17
Menado	.31	.28	.36	.46	.49	.40	.46	.48	.45	.48	.46	.34
Pontianak	.20	.15	.15	.17	.24	.25	.32	.31	.16	.14	.13	.14
Brindisi/Casale	.37	.34	.39	.50	.54	.65	.78	.81	.70	.51	.46	.42
Hato	.71	.65	.53	.45	.44	.39	.48	.54	.50	.45	.48	.56
Puerto Princesa	.42	.47	.56	.54	.39	.23	.19	.21	.24	.31	.33	.37

TABLE 5. Conditional Probability of a 5-minute CFLOS for a geostationary satellite orbiting at a longitude of 80° E, Sun angles 12° and 18° below the horizon.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Learmonth	.54	.56	.61	.60	.64	.62	.72	.74	.81	.79	.73	.70
Brisbane	.27	.27	.34	.38	.37	.45	.47	.50	.49	.37	.29	.27
Woomera	.65	.62	.65	.70	.55	.53	.58	.63	.61	.62	.58	.62
Darwin	.16	.17	.21	.43	.61	.62	.63	.63	.56	.52	.36	.25
Broome	.19	.18	.29	.52	.51	.59	.62	.67	.63	.59	.51	.36
Cairns	.28	.23	.28	.37	.34	.49	.48	.48	.46	.44	.42	.35
Meekatharra	.58	.52	.59	.57	.63	.66	.66	.68	.77	.71	.69	.63
Bali/Ngurah	.22	.27	.34	.44	.49	.48	.51	.52	.51	.50	.42	.29
Hasanuddin/Ujung	.16	.18	.22	.33	.42	.43	.53	.61	.56	.55	.37	.20
Menado	.33	.30	.32	.49	.47	.43	.47	.48	.49	.51	.48	.37
Pontianak	.22	.17	.17	.19	.25	.28	.33	.31	.19	.18	.15	.16
Puerto Princesa	.41	.47	.53	.54	.37	.24	.19	.23	.25	.34	.36	.41

TABLE 6. Conditional Probability of a 5-minute CFLOS for a geostationary satellite orbiting at a longitude of 100° E, Sun angles 12° and 18° below the horizon.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Learmonth	.58	.58	.62	.63	.65	.62	.72	.75	.83	.80	.76	.71
Brisbane	.38	.39	.46	.51	.49	.57	.56	.61	.59	.49	.40	.39
Woomera	.68	.64	.66	.67	.57	.57	.60	.65	.64	.66	.64	.65
Darwin	.18	.20	.24	.46	.64	.65	.67	.65	.60	.52	.38	.27
Broome	.21	.21	.32	.53	.54	.61	.64	.69	.64	.62	.52	.38
Cairns	.34	.29	.35	.42	.40	.53	.54	.54	.52	.51	.40	.47
Meekatharra	.58	.53	.60	.57	.65	.66	.68	.69	.77	.71	.66	.72
Bali/Ngurah	.24	.29	.41	.43	.55	.49	.54	.52	.53	.49	.45	.32
Hasanuddin/Ujung	.17	.20	.26	.35	.44	.45	.56	.64	.58	.57	.38	.22
Menado	.34	.33	.36	.51	.51	.44	.49	.52	.50	.53	.50	.38
Pontianak	.22	.19	.19	.19	.27	.29	.35	.33	.20	.19	.15	.18
Puerto Princesa	.42	.50	.56	.55	.39	.25	.22	.26	.25	.35	.36	.43

TABLE 7. Conditional Probability of a 5-minute CFLOS for a geostationary satellite orbiting at a longitude of 120° E, Sun angles 12° and 18° below the horizon.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Learmonth	.58	.58	.62	.64	.65	.63	.73	.75	.83	.80	.73	.72
Brisbane	.42	.43	.47	.54	.52	.59	.59	.64	.63	.49	.44	.44
Woomera	.69	.65	.68	.67	.59	.57	.62	.65	.64	.68	.64	.67
Darwin	.20	.20	.25	.47	.64	.66	.68	.68	.61	.57	.41	.28
Broome	.23	.21	.36	.51	.56	.62	.65	.68	.66	.61	.55	.40
Cairns	.36	.30	.41	.41	.44	.56	.56	.53	.55	.51	.51	.45
Meekatharra	.57	.53	.57	.61	.65	.66	.68	.72	.76	.74	.71	.64
Bali/Ngurah	.23	.30	.38	.46	.52	.51	.55	.55	.53	.53	.45	.32
Hasanuddin/Ujung	.18	.21	.29	.34	.47	.46	.58	.63	.61	.56	.41	.24
Menado	.37	.34	.41	.50	.54	.46	.52	.51	.53	.52	.54	.42
Pontianak	.23	.18	.22	.18	.28	.28	.36	.31	.21	.17	.15	.18
Puerto Princesa	.45	.51	.60	.54	.42	.25	.23	.23	.27	.34	.39	.45

TABLE 8. Conditional Probability of a 5-minute CFLOS for a geostationary satellite orbiting at a longitude of 140° E, Sun angles 12° and 18° below the horizon.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Learmonth	.57	.56	.59	.61	.64	.62	.71	.75	.82	.79	.74	.71
Brisbane	.42	.43	.50	.57	.55	.62	.63	.65	.62	.53	.48	.44
Woomera	.67	.68	.69	.67	.60	.58	.63	.66	.65	.66	.63	.66
Darwin	.20	.20	.24	.50	.64	.66	.68	.66	.62	.62	.41	.27
Broome	.22	.22	.33	.54	.55	.62	.65	.69	.67	.62	.53	.39
Cairns	.37	.33	.39	.46	.45	.57	.58	.57	.58	.55	.50	.45
Meekatharra	.58	.55	.58	.61	.65	.66	.68	.82	.79	.75	.69	.64
Bali/Ngurah	.23	.29	.37	.45	.52	.49	.53	.53	.54	.51	.44	.31
Hasanuddin/Ujung	.17	.20	.26	.35	.45	.45	.56	.64	.61	.57	.39	.23
Menado	.36	.34	.38	.52	.53	.46	.51	.52	.54	.54	.52	.41
Pontianak	.22	.17	.18	.18	.26	.27	.34	.50	.19	.17	.14	.17
Puerto Princesa	.43	.51	.57	.55	.41	.25	.21	.24	.26	.34	.37	.43

TABLE 9. Conditional Probability of a 5-minute CFLOS for a geostationary satellite orbiting at a longitude of 160° E, Sun angles 12° and 18° below the horizon.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Learmonth	.54	.54	.58	.59	.63	.60	.70	.74	.80	.78	.73	.68
Brisbane	.44	.43	.51	.57	.54	.63	.62	.65	.62	.52	.45	.45
Woomera	.69	.66	.69	.68	.59	.57	.61	.66	.64	.68	.65	.67
Darwin	.18	.19	.23	.46	.64	.64	.67	.66	.60	.53	.40	.29
Broome	.19	.20	.30	.51	.51	.59	.63	.66	.63	.59	.50	.37
Cairns	.37	.32	.37	.44	.43	.57	.57	.55	.55	.54	.51	.44
Meekatharra	.56	.52	.55	.57	.61	.65	.67	.68	.76	.72	.68	.62
Bali/Ngurah	.20	.26	.33	.40	.47	.46	.49	.48	.48	.47	.39	.28
Hasanuddin/Ujung	.15	.18	.23	.31	.41	.43	.53	.59	.55	.53	.35	.20
Menado	.34	.32	.34	.48	.48	.44	.48	.48	.49	.51	.49	.38
Pontianak	.18	.15	.15	.16	.22	.24	.31	.26	.16	.15	.12	.15
Puerto Princesa	.41	.48	.53	.51	.36	.23	.19	.21	.23	.32	.34	.41

TABLE 10. Conditional Probability of a 5-minute CFLOS for Hato, Netherlands Antilles, for a geostationary orbiting satellite at the given longitudes, Sun angles 12° and 18° below the horizon.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20° W	.69	.61	.52	.45	.41	.42	.51	.53	.51	.47	.51	.54
40° W	.72	.65	.59	.48	.45	.45	.54	.57	.53	.50	.53	.57
60° W	.74	.67	.61	.48	.47	.46	.55	.57	.56	.51	.56	.62
80° W	.74	.67	.59	.51	.48	.47	.56	.58	.59	.52	.55	.61
100° W	.73	.64	.57	.47	.43	.44	.54	.54	.53	.49	.51	.58

TABLE 11. Conditional Probability of a 5-minute CFLOS for Brindisi, Italy, for a geostationary orbiting satellite at the given longitudes, Sun angles 12° and 18° below the horizon.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
40° W	.42	.38	.44	.47	.52	.66	.77	.73	.70	.55	.43	.44
20° W	.42	.39	.46	.51	.55	.66	.77	.75	.74	.56	.48	.46
0° W	.41	.37	.46	.47	.54	.66	.77	.74	.71	.53	.48	.44
20° W	.39	.36	.43	.47	.53	.64	.76	.74	.68	.53	.44	.42
40° W	.36	.32	.39	.45	.49	.61	.73	.70	.66	.49	.43	.38

3.2 How to Use the Tables. Data provided in the various tables can be used to calculate the joint probability of all five of the conditions *A-E*. From the definition of conditional probability, several expressions can be obtained:

$$P(ABCDE) = P(E/ABCD) \cdot P(ABCD) \quad (1)$$

$$P(ABCD) = P(D/ABC) \cdot P(ABC) \quad (2)$$

$$P(ABC) = P(C/AB) \cdot P(AB) \quad (3)$$

$$P(AB) = P(B/A) \cdot P(A) \quad (4)$$

Substituting (2) into (1) yields:

$$P(ABCDE) = P(E/ABCD) \cdot P(D/ABC) \cdot P(ABC) \quad (5)$$

Combining this expression with (3) and (4) results in:

$$P(ABCDE) = P(E/ABCD) \cdot P(D/ABC) \cdot P(C/AB) \cdot P(B/A) \cdot P(A) \quad (6)$$

Condition *D* is independent of conditions *A, B*, and *C;* as a result, we can say that $P(D/ABC) = P(D)$. Also, since $P(B) = 1$ and $P(C) = 1$, their conditional probabilities will always be unity, or $P(B/A)$ and $P(C/AB) = 1$, respectively. Therefore, equation 6 can be written as:

$$P(ABCDE) = P(E/ABCD) \cdot P(D) \cdot P(A) \quad (7)$$

Using equation 7, we can now substitute data from Table 4b for $P(E/ABCD)$, Table 3 for $P(D)$, and Table 1b for $P(A)$.

3.3 Sample Calculation. To compute the probability that a satellite in the 19,000-km polar orbit can be detected by the GEODSS system at Learmonth during January given that the satellite elevation angle is at least 20° and that the Sun elevation angle is at least 18° below the horizon:

- Get $P(A)$ from Table 1b (0.33)
- Get $P(D)$ from Table 3 (0.21).
- Get $P(E/ABCD)$ from Table 4b (0.54)

Substituting in Equation 7,

$$P(ABCDE) = P(E/ABCD) \cdot P(D) \cdot P(A)$$

$$P(ABCDE) = (0.54) * (0.21) * (0.33)$$

$$P(ABCDE) = 0.04$$

This shows that there is only a 4% chance that weather conditions will permit detection of the satellite when it is in view at Learmonth in January. In contrast, the Learmonth probability from July to December is 7%. The difference between probabilities for sun angles 12° below the horizon and those for Sun angles 18° below the horizon is negligible. Table 12 gives probabilities by month (for sun angles of 12 and 18° below the horizon) for all 14 sites.

TABLE 12. Unconditional Probability of joint occurrence of *Conditions A, B, and C.* Condition *A*--Sun at least 12° or 18° below the horizon; *B*--surface wind speeds less than 25 knots; *C*--temperature higher than -50° C; *D*--satellite's elevation angle at least 20° above the horizon; and *E*--5-minute CFLOS between an object in a 19,000 km orbit (right ascension angle of 65°) and the ground.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Learmonth	.04	.04	.05	.06	.06	.06	.07	.07	.07	.07	.06	.05
Brisbane	.03	.03	.04	.05	.05	.06	.06	.05	.05	.04	.04	.03
Woomera	.05	.05	.06	.06	.06	.06	.06	.06	.06	.05	.05	.05
Darwin	.01	.01	.02	.04	.05	.05	.05	.05	.04	.04	.03	.02
Broome	.02	.02	.03	.05	.05	.06	.06	.07	.06	.05	.04	.03
Cairns	.03	.03	.03	.04	.04	.05	.05	.05	.05	.05	.04	.03
Meekatharra	.05	.05	.04	.06	.07	.07	.07	.07	.07	.06	.05	.05
Bali/Ngurah	.01	.02	.03	.03	.04	.03	.04	.04	.04	.03	.03	.02
Hasanuddin/Ujung	.01	.01	.01	.02	.03	.02	.03	.03	.03	.03	.02	.01
Menado	.02	.01	.02	.02	.03	.02	.02	.02	.02	.03	.02	.02
Pontianak	.01	.01	.01	.01	.01	.01	.02	.02	.01	.01	.01	.01
Brindisi	.02	.02	.02	.02	.02	.02	.03	.03	.03	.03	.03	.03
Hato	.06	.06	.05	.04	.04	.03	.04	.04	.04	.04	.04	.05
Puerto Princesa	.03	.04	.04	.04	.03	.02	.01	.02	.02	.02	.03	.03

4. DISCUSSION

4.1 Conditional vs Unconditional Probabilities. Comparing the conditional probabilities in Tables 4a&b (polar-orbiting satellite) with those in Tables 5 through 9, (geostationary satellite), we can see consistency in the reported values for each station. For example, the probability in Table 4b for Learmonth for September and the probabilities in Tables 5-9 for September are all around 82 percent. When we introduce *unconditional* probabilities, the probability of detecting geostationary satellite is constrained only by *P(D)*, or the probability of the satellite's being in view. The unconditional probabilities for a polar orbiting satellite show an 80% reduction in Table 12 from Tables 4a through 4b. Note that Tables 4a and 4b are similar.

4.2 Station vs Station. Inspection of the probabilities for each station shows that the environment has a definite effect on satellite detection. The frequency distribution of mean sky cover for Learmonth indicates that the sky is predominantly clear, while the distribution for Darwin is flatter, implying cumulus cloudiness. These results are consistent with Learmonth's desert location and the influence of the Intertropical Convergence Zone's movement. on Darwin. Although Brisbane's climate is moderate, its coastal location, with onshore frontal and land/sea trough events, results in variable cloud-cover. Woomera, although at a more temperate latitude than Brisbane, is more arid (since it is farther inland) and less cloudy.

5. CONCLUSIONS

5.1 Summary of Results. The study suggests that four stations in Australia (Learmonth, Meekatharra, Woomera, and Broome) appear to be the best choices for a GEODSS site, at least from an environmental standpoint.

5.2 Probability of a 5-minute CFLOS for a Geostationary Orbiting Satellite. Tables 5-9 show that Learmonth has better conditional probabilities than the other stations from May through December; for 6 of these 9 months, the probabilities *P(E/ABCD)* at Learmouth are 70% or greater. For the other 2 months, the probability is greater than 80%. The only other station with probabilities in the 70% or better range is Meekatharra, the next best choice. Meekatharra has steady values of 60 to 70 percent for *P(E/ABCD)* from April to December. Its dry climate and inland location explain its consistent probabilities throughout the year. Woomera's conditional probabilities are better from January through April, while Learmonth and Meekatharra are better during the remaining months. None of the other sites compares with those mentioned above. Brindisi, Italy, has some good results, but only for 4 months.

5.3 Probability of a 5-Minute CFLOS of a Polar Orbiting Satellite. Calculating the unconditional (joint) probabilities for a polar orbiting satellite introduces a significant factor--satellite elevation constraints. Table 12 again reveals that Learmonth and Meekatharra are consistently best, closely followed by Woomera and Broome.

BIBLIOGRAPHY

Bartholemew and Sons Limited and Times Books Limited, *The Times Atlas of the World*, 7th Ed., Times Books, New York, 1985.

Boehm, A.R., *Transnormalized Regression Probabilities*, AWS-TR-75-259, Air Weather Service, Scott AFB, IL, 1975.

Burger, C.F., *World Atlas of Total Sky-Cover*, AFGL-TR-85-0198, Air Force Geophysics Laboratory, Hanscom AFB, MA, 1985.

Rupp, J.A., *CLDGEN Users Guide*, USAFETAC/TN-90/003, United States Air Force Environmental Technical Applications Center, Scott AFB, IL, 1990.

Warren, A.J., *Optimal Placement of a GEODSS (Ground-Based Electrooptical Deep-Space Surveillance Sensor)*, USAFETAC/TN-91/018, United States Air Force Environmental Technical Applications Center, Scott AFB, IL, 1991.

ACRINABs

ACRINAB	Acronym, initialism, or abbreviation
BMAT	Beginning of morning astronomical twilight
BMCT	Beginning of morning civil twilight
BMNT	Beginning of morning nautical twilight
CFLOS	Cloud-free line-of-sight
CLDGEN	Cloud scene generator model
EEAT	End of evening astronomical twilight
EECT	End of evening civil twilight
EENT	End of evening nautical twilight
GEODSS	Ground-based electrooptical deep-space surveillance
P	Probability

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